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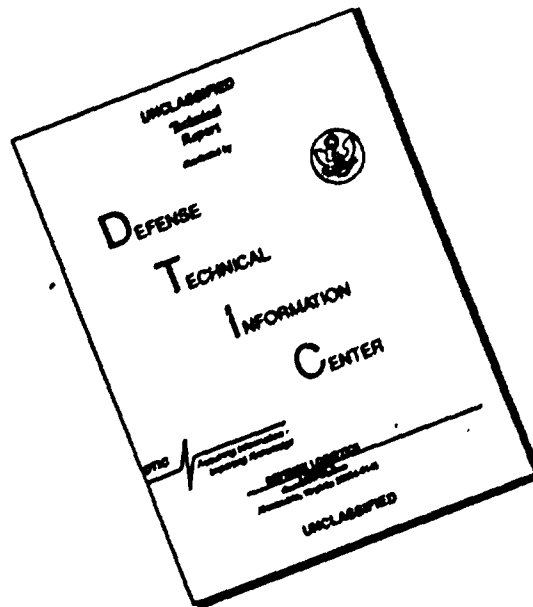
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ROYAL AIRCRAFT ESTABLISHMENT

Technical Report 68254

October 1968

WARHEAD SIZE DETERMINATION

by

F. Bisby

SUMMARY

A hypothesis is suggested for guidance in weapon design, that the best warhead size for the attack of a specified target is the threshold size required for a direct hit to produce a kill. It is based upon the fact that this threshold size is one or more orders smaller than that required to cater for near-misses and that this economy in warhead size can be exploited to increase the chance of getting a direct hit, either by increasing delivery accuracy or by deploying more weapons, thereby leading to greater weapon effectiveness. Multi-weapon deployment modes are discussed, leading in particular to the further principle that for weapons which have to be delivered in one attack opportunity, e.g. unguided air-to-surface weapons, the most efficient attack is with a spaced salvo of threshold weapons.

It is not claimed that the hypothesis is universally true. Whether it leads to a more effective weapon in any specific case will always require evaluation. Furthermore, it may be more applicable to air-to-surface weapons, mainly referred to as examples in this paper, than to other weapon types, such as anti-aircraft weapons, for which the warhead is a less dominant component.

Departmental Reference: WE.158

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CONTENTS

1   INTRODUCTION

1.1   Warhead optimisation

The question of warhead size optimisation constantly recurs in weapon design.   Given the necessary functional relationships between the relevant parameters, in particular between warhead size on the one hand and lethality, accuracy and number of weapons deployable on the other, it should be possible to derive an optimum warhead size by the standard mathematical optimisation process.   The difficulty lies in writing down these relationships in a form simple enough to be tractable and yet adequately realistic.   An attempt at this type of solution is made in Appendix A, more in the way of an example to show that this approach is not a profitable one and can in fact lead to non-sensical answers, the reason being that the relationships are inadequate, particularly in one important respect which will emerge later.

An alternative approach is to take a particular situation and to evaluate the kill chances for a range of sizes of warhead to see which gives the best result.   An example of this approach is given in Ref.1.   It can give valuable guidance for the particular situation investigated but it has the drawback that its solutions are usually determined by the particular constraints speci-fied and, therefore, that it does not give any insight into the general problem, such as would lead to more universally applicable principles.

1.2   A hypothesis on warhead size

A hypothesis is put forward in this paper to provide guidance in the choice of warhead size for any given weapon design.   Briefly the hypothesis is that it does not pay to cater for near-misses; more formally that the best war-head size is the minimum size required for a direct hit on the target to cause the required damage.

The hypothesis is not necessarily true in all cases and it will always be a matter for evaluation as to whether the cost of achieving a direct hit outweighs the advantage accruing from it.   Furthermore, it may be more relevant to one type of weapon than another, for instance to air-to-surface weapons rather than to surface-to-air weapons, since the warhead is a more dominant missile component in the former.   Nevertheless, this paper will indicate that the relationship between lethal range and warhead size against most targets is such that the 'threshold' size for a direct hit is an order or several orders smaller than that required for near-misses; that this advantage in size can be

exploited to increase the chance of getting a direct hit, either by increasing
the number of weapons deployed or by increasing the delivery accuracy; and that
this generally results in an overall gain in weapon effectiveness for a given
weapon penalty in either weight or cost. This is particularly so for short-
range unguided air-to-surface weapons for which the principle can be extended
as follows: that the most efficient attack is with a spaced salvo of weapons
whose warheads are of threshold size for direct hits.

2   THE TARGET VULNERABILITY CURVE

2.1   General form

The crux of the argument in this paper is that there is a peculiarity
about target vulnerability which immediately points the way to the optimum war-
head size. This peculiarity is best described by reference to the target vulnera-
bility curve in Fig.1, where the warhead size required for a 'kill', i.e. to
cause some specified damage to the target, is plotted against distance from
target centre to weapon impact point. No scales are put on the diagram because
these will depend upon the particular target and type of warhead involved
and the diagram is intended to depict a general form of relationship between
critical warhead size and miss-distance which applies to any target, although
a modification may be required for ship targets (see section 2.5 below).

For strikes on the target itself, henceforward referred to as 'direct-
hits', a certain warhead size is required for a kill which is broadly constant
wherever the hit occurs; but as soon as the impact point moves outside the
target, into what is henceforward referred to as the region of 'near-misses',
there is a big jump in the required warhead size, by about an order of magni-
tude, and as the miss-distance increases further the required warhead size rises
rapidly, usually following some power law, typically the square or the cube of
the miss-distance.

2.2   Physical explanation

There is a simple explanation of these features of the target vulnera-
bility curve. The total chemical energy of a charge detonated internally, as
well as the kinetic energy of the missile which delivered it, can be applied
as a disruptive force to the target structure and contents, whereas for
external explosions only that fraction of the explosive energy directed at
the target can be so applied. By simple geometry this fraction is inversely

proportional to the square of the miss-distance and furthermore the energy is
attenuated by the medium through which it passes, so that the proportion of the
explosive energy eventually applied to the target decreases rapidly with
miss-distance.

There are two additional factors which accentuate the discrepancy between
the critical warhead sizes for internal and external explosions. The first is
that energy applied asymmetrically from outside can often be absorbed by lateral
movement of the whole or part of the target structure, thus reducing structural
disruption. The second is that certain lethality-improving devices, such as
shaped-charges, squash-heads and incendiary material, require contact with the
target to be effective and can therefore only be used with direct hitting
warheads (of course relatively large shaped-charges can be effective at rela-
tively large stand-offs and may not therefore require direct-hitting but do
require aligning in the target direction).

2.3   Examples

The foregoing explanation, based as it is on physical laws, is sufficient
by itself to justify the acceptance of Fig.1 as the fundamental form of the
target vulnerability curve. Nevertheless, the provision of even one specific
example of a well-established complete curve has been found well-nigh impossible,
simply because the necessary target vulnerability data is not available. Apart
from the aircraft vulnerability curve in Fig.7, therefore, supporting evidence
can only be given in the form of occasional spot points and a few such examples
are given in Appendix B.

2.4   The difficulties of mathematical optimisation

If the target vulnerability curve of Fig.1 is accepted - and henceforward
in this paper it will be tacitly assumed that this is so - then the discontinuity
at the edge of the target provides an immediate explanation of the difficulty
of determining an optimum warhead size by a mathematical optimisation procedure
such as that attempted in Appendix A. The power law assumed in Appendix A,
in fact, only represents the near-miss portion of the vulnerability curve and
ignores the direct-hit portion and the discontinuity at the edge of the target,
the very features, it is argued here, which provide the clue to the true
optimum warhead size. Such an over-simplified representation then leads to some
absurd conclusions, such as that derived in Appendix A that the optimum weapon
for the attack of heavy structural targets (dams, tunnels, bridges) is a cluster

of small bomblets each weighing a few pounds; because it assumes that the power
law representing the near-miss portion of the vulnerability curve holds for all
values of warhead size whereas, in fact, the power law breaks down for values
below the threshold size and this threshold size can be quite large (order of
1000 lb) for these structural targets.

2.5 Modification for ship target

The possibility was mentioned in section 2.1 of the vulnerability curve
needing modification for ship targets. A ship target differs from land or air
targets in that a relatively small hole in a particular part, namely below water
level, will allow flooding and thereby result in a higher category of damage
than is warranted by the purely structural damage to the ship. An extreme
example is the submarine, where the flooding caused by a hole in the pressure
hull an inch or two in diameter may be beyond the capacity of the pumps and
therefore constitute Category A damage. A full description of ship target
vulnerability, in fact, requires two curves for the near-miss portion; one for
air-bursts, which will have the same characteristics as that shown in Fig. 1;
and another for underwater bursts, starting at a lower level than the air-burst
curve for bursts in contact with, or very near to, the ship's plating and then
increasing as the square of the distance (according to the well-known 'shock
factor' for underwater bursts) - the starting point may in some cases be below
the level for internal detonations.

3   THE EXPLOITATION OF THE THRESHOLD WARHEAD SIZE

3.1 Methods of exploitation

The minimum warhead size required to give a kill for a direct-hit on the
target (or some specific part of the target) will be referred to as the 'threshold
size' and it will be assumed that it is at least an order, and may be several
orders, smaller than any warhead designed to have a near-miss capability. To
establish the 'threshold hypothesis' enunciated in section 1.2 requires an
exploitation of this advantage in warhead size so that, in comparison with the
aforementioned near-miss weapon, an increase is achieved in the chance of getting
a direct-hit and on balance thereupon an increase in overall weapon lethality
in a specified set of attack conditions. There are two methods of exploitation:-

  (1) by increasing weapon delivery accuracy, and

  (2) by increasing the number of weapons deployed.

The author's interest is mainly in air-to-surface weapons and for that reason the following discussion is mainly concerned with the application of the threshold hypothesis to these weapons, although there appears to be no reason why it should not apply to other weapons. For unguided air-to-surface weapons, such as bombs, rockets and guns, exploitation by numbers is the only possible method since the delivery accuracy of such weapons is largely determined by the aircraft's navigation/attack system and is therefore practically independent of missile size. The important penalty with airborne unguided weapons is weight, weapon costs being relatively small compared with aircraft and sortie costs, and valid comparisons of different weapon sizes can, therefore, be made on the basis of a given aircraft payload. Both exploitation methods are possible, however, for guided weapons (although physical factors such as glint and system noise may put a limit on the achievable accuracy) and furthermore comparisons of warhead sizes may have to be made on a cost as well as a weight basis. The two types of weapon therefore require separate consideration in this context, but before going on to do this in the next two sections it is convenient to consider the problem, common to any weapon exploiting by numbers, of the most efficient weapon deployment mode for a multi-weapon attack.

3.2   Multi-weapon deployment modes

There are in fact three distinct weapon deployment modes,

(1)   Independent aiming – in which each weapon is aimed separately and independently at the target.

(2)   Delivering a spaced salvo – in which the weapons are deliberately spaced in a pattern whose centre is aimed at the target.

(3)   Delivering a random salvo – in which the weapons are all delivered with the same aim and weapon dispersion is relied upon to give a spread of impact points, generally in a bivariate normal distribution.

The derivation of the kill chance for these three modes is discussed in

Appendix A and Fig.2 plots kill chance against the parameter $\left(\dfrac{NR^2}{S^2}\right)$ for each mode,

where N is the number of weapons to be deployed,

       R is the radius of the target, assumed circular, and

       S is the standard deviation of the delivery error whose distribution
is assumed to be unbiassed, circular and bivariate normal.

For this idealised case it is shown in Appendix A that independent aiming and
the ideal spaced salvo modes yield the same result and therefore are represented
by the same curve in Fig.2. Furthermore, comparison with the curve for the
random salvo mode shows that the two former modes are more efficient than the
latter.

4   APPLICATION TO UNGUIDED AIR-TO-SURFACE WEAPONS

       Independent aiming is not generally acceptable for a multi-weapon air-to-
ground attack from a fixed wing aircraft since it would entail either repeated
passes by one aircraft or a single pass by a number of aircraft and in either
case multiple exposure of aircraft to enemy defences. In these circumstances,
the result enunciated in the last paragraph is clearly an important one since
it means that a strike aircraft can, by using the spaced salvo, deliver its
full weapon quota for one target <u>in one pass</u> and <u>with maximum efficiency</u> with
respect to weapon deployment mode. Thus the general hypothesis can be particu-
larised as follows: <u>that for weapons which must be delivered in one attack</u>
<u>opportunity</u> - in particular unguided air-to-surface weapons - <u>the most efficient</u>
<u>attack is with a spaced salvo of weapons whose warheads are of the threshold</u>
<u>size for direct hits.</u>

       The most common instance of the spaced salvo is, of course, the "stick of
bombs" which, with optimum spacing, is the ideal spaced salvo in one dimension
only, namely along-track, and is well-suited to the beam attack of long targets,
such as ships and bridges, where the across-track errors are absorbed by the
target length. The British cluster weapon is an attempt to achieve the ideal
spaced salvo in both dimensions and indeed is an example - probably the only
one to-date - of the intentional application of the principle just enunciated.

5   APPLICATION TO GUIDED WEAPONS

       Both methods of exploitation mentioned in section 3.1 are possible with
a guided weapon, the first in the obvious way,

       (1) by matching the guidance system to a single-shot attack with a weapon
having a single warhead of threshold size, i.e. relying on high accuracy to

achieve a high chance of a direct hit with a single warhead; in some instances
it may be that the limit on achievable accuracy precludes this solution,
e.g. for S.A.G.W. where target glint and system noise tend to put a lower
limit on the achievable miss distance;

the second in two ways,

(2) by deploying a number of cheaper and less accurate weapons than
that of (1) above, each with a warhead of threshold size, and relying to some
extent on numbers to achieve a direct hit - in this case the independent
aiming mode is possible, or

(3) by using a cluster type warhead, the bomblets being of threshold
size, on a larger missile than those of (1) or (2) above - in fact, this is
the same solution as that for the unguided air-to-surface weapon, namely the
use of a spaced salvo, but we must now define S as the missile delivery
error instead of the aircraft delivery error.

The choice between these three ways must be determined by the task required of
the weapon, but in general the third would appear to have the widest application
and to be the easiest to apply. The first, for instance, may be too difficult
and too costly, and in choosing between the second and third the economic
advantage of guiding a number of warheads in one package rather than individually
will certainly favour the third. However, the third way implies putting all
one's eggs in one basket and the second way has the advantage of being less
vulnerable to the hazards of guidance system unreliability and target defences.

6   JUSTIFICATION ON EFFECTIVENESS GROUNDS

6.1   General

So far the case for the threshold hypothesis has rested on the advantage
in warhead size of a direct hit weapon over one designed to have near-miss
capability, but for a proper justification it is necessary to show that this
results in an overall advantage in effectiveness. It is argued in section 2.2
that the advantage in size arises from the fundamental laws of physics. The
question of effectiveness, however, depends upon the quantitative balancing
of the warhead advantage against the accompanying disadvantage of needing to
get a direct hit and there are no fundamental laws governing the relationship
between these two opposing tendencies and hence no way of demonstrating analy-
tically that the threshold hypothesis is necessarily true. Its justification
must therefore rest on comparative effectiveness evaluations in specific cases.

6.2 Evidence on unguided weapons

It must be admitted that evidence along these lines is very scanty and that that which is available is restricted to the case of the attack of close-support targets by short-range unguided weapons. This evidence is summed up in Figs.3 and 4, taken from Ref.2, and shows that a cluster weapon, designed on the threshold hypothesis, has a clear advantage in effectiveness per unit weight of weapon over 540 and 1000 lb bombs, despite the latter's near-miss capability.

Against the structural interdiction targets, such as bridges, dams, tunnels, ships and railways, the evidence is confusing. There have been comparisons of different sized bombs, e.g. a stick of 3 × 1000 lb bombs against a single 2500 lb [3], and in general the results indicate an advantage to the smaller calibre, although not very mark'd. However, these assessments are not quite relevant to the issue under consideration, since they are generally based on the assumption that the targets are only vulnerable to direct hits whatever the size of bomb, the differences in size only affecting the chance of achieving a certain damage level given a hit... In fact these targets are such that the normal run of H.E. weapons, say limited to 3000 lb, the maximum load on current strike aircraft pylons, can have little or no near-miss capability and the right hand side of the target vulnerability curve could therefore only be relevant to nuclear weapons. If consideration were extended to nuclear warheads then to be consistent the comparison should be between say a megaton near-miss warhead weighing the order of 1000 lb and whatever sized nuclear warhead would cause the same damage given a direct hit and this presumably would be a sub-kiloton warhead weighing only the order of ten pounds. Then the 'structural' target attacked by nuclear weapons would present the same picture as the 'light' target attacked by H.E. weapons and the threshold principle would lead to the conclusion that the most economical attack is with a cluster of sub-kiloton bomblets.

6.3 Evidence on guided weapons

The author is unaware of any relevant evidence, in the form of comparative effectiveness evaluations, to justify the threshold hypothesis when applied to guided weapons, although two recent British designs of guided weapons could be put forward as examples of high-accuracy direct-hitters with threshold sized warheads and impact fuses: namely the A.S.G.W. Martel (TV version) for the attack of interdiction targets such as ships and bridges and the S.A.G.W. Rapier for the attack of low-flying aircraft. The anti-radar version of Martel

on the other hand cannot achieve the required accuracy to give a high chance of a hit on its target, the radar antenna, and since the missile can incorporate a big enough warhead to have a considerable near-miss effect then this is used together with an appropriate proximity fuse. The threshold warhead size for direct hits on the antenna would presumably be much smaller and in this case the solution suggested by the threshold hypothesis would be either to have a cluster warhead on the existing missile deploying bomblets of threshold size by means of the proximity fuse or to fire a larger number of smaller missiles each carrying a single warhead of threshold size and an impact fuse. It is a matter for evaluation as to how these two solutions compare on a cost/effectiveness basis with the present design, but on the face of it the second solution would appear to be uneconomical and the first solution probably a strong competitor.

7   CONCLUSIONS

To sum up: the threshold hypothesis is put forward in the belief that it is a good working guide. There is very little supporting evidence, but its validity really rests upon,

(1)   the fact, itself based upon the fundamental laws of physics, that the threshold warhead size is much smaller than that required to cater for near-misses, and

(2)   the opportunity thereby offered to exploit this advantage in warhead size to increase the chance of a direct hit either by increasing delivering accuracy or by increasing the number of weapons deployed.

Since it cannot be shown to be universally true, the application of the threshold hypothesis to any specific set of circumstances must always be a matter for evaluation. Nevertheless it is suggested that in formulating proposals for any new weapon it would be worthwhile considering whether a weapon designed on the threshold hypothesis provides the best solution.

ACKNOWLEDGEMENT

SECRET-DISCREET

Appendix A

MATHEMATICAL WARHEAD OPTIMISATION

A.1   To find an optimum warhead weight by means of the standard mathematical
procedure requires weapon effectiveness to be expressed as a function of war-
head weight. Consider the idealised case of a point target attacked by a weapon
whose lethal range is R (or the identical case of a target of radius R
attacked by a weapon with a warhead of threshold size) and a delivery error
distribution which is circular, bivariate normal and unbiassed with standard
deviation S. Then the kill chance for a single shot is

$$P_{KSS} = 1 - \exp\left\{-\frac{R^2}{2S^2}\right\} \qquad (1)$$

and if N such weapons are independently aimed at the target then

$$P_{KN} = 1 - (1 - P_{KSS})^N$$

$$= 1 - \exp\left\{-\frac{NR^2}{2S^2}\right\} \qquad . \qquad (2)$$

Thus N weapons of lethal radius R independently aimed at a target are
exactly equivalent in kill chance to a single weapon of lethal radius $N^{\frac{1}{2}}R$.
The ideal spaced salvo will be so designed that the lethal areas of the N
weapons are compactly grouped with no overlap and no gaps, to give a total
lethal area of $N\pi R^2$, showing that the ideal spaced salvo and independent
aiming yield the same result. The random salvo is not so easily dealt with
because an additional parameter must be introduced, namely the weapon disper-
sion within the salvo, say σ. However, it can be shown[4] that for given
values of N, R and S there is an optimum value of σ and if it is
assumed for the ideal case that σ has been optimised then P_K is a monotonic
increasing function of $\frac{NR^2}{S^2}$ as plotted in Fig.2, where is also plotted the

P_K for the independent aiming and ideal spaced salvo weapon deployment modes
as given by expression (2) above. (To avoid misunderstanding regarding the
claimed equivalence of the spaced salvo and independent aiming the foregoing
should be qualified by pointing out that the criterion of effectiveness is the

chance of at least one hit on a vulnerable area and that, for instance, the
spaced salvo would be inferior to independent aiming if the criterion were the
total cumulative damage to the target, or the expected number of hits on the
target. Furthermore, the spaced salvo is assumed above to be the ideal one
with no overlap and no gaps between the lethal areas achieved by its compo-
nents; this is well nigh impossible to achieve in practice due to irregularity
of weapon spacing and the usually inappropriate shape of lethal areas. Thus,
where it is possible, and other things being equal, independent aiming should
always be preferred to the spaced salvo.)

A.2   The specific case will now be considered of the unguided air-to-surface
weapon, for which S is largely determined by the aircraft's weapon delivery
system and can therefore be regarded as independent of warhead weight. Thus
the optimisation process need only concern itself with the expression NR^2 and
the requirement therefore is to express N and R as functions of the warhead
weight W.

A.3   The simplest relationship for N is to make it inversely proportional
to W, but this ignores the packaging problem, i.e. the fact that there are
certain weight overheads which are largely independent of W and which
therefore result in a relationship of the form,

$$N = \frac{A}{B + W} \tag{3}$$

where A and B are empirical constants, A being some overall weight
restriction such as the payload of an aircraft and B the weight overhead
for each weapon.

A.4   Empirical data[5] suggests a relationship for R of the form

$$R = CW^n \tag{4}$$

and it is possible to justify this theoretically for some damage criteria.
Combining (3) and (4) gives the effectiveness parameter NR^2 in terms
of W namely,

$$NR^2 = AC^2 \left(\frac{W^{2n}}{B + W} \right) \tag{5}$$

from which the following criteria can be derived:-

<u>when $n \geqslant \frac{1}{2}$,</u> the kill chance increases monotonically with W and the optimum

warhead weight is therefore the largest possible, namely

$W_{OPT} = (A - B)$ and then $N = 1$,

<u>when $n < \frac{1}{2}$,</u> equating to zero the derivative of 5 with respect to W gives,

$$W_{OPT} = \left(\frac{2n}{1 - 2n}\right) B \tag{6}$$

For instance a common value of n is $\frac{1}{3}$ giving a value for W_{OPT} of 2B. B is normally a very small fraction of A (e.g. for the 600 lb cluster weapon containing $147 \times 2\frac{1}{2}$ lb bomblet, $B = 1.6$ lb) so that gives a W_{OPT} of a few pounds weight.

A.5   The procedure outlined above therefore leads to the result that the best way to attack a target is either with a single large weapon or with a large number of small weapons according to whether the value of n in equation (4) is greater or smaller than $\frac{1}{2}$. This result would be credible if it meant that the single large weapon solution applied to the massive structural type target and the small multi-weapon solution applied to the light battlefield target, i.e. if the value of n for these targets were respectively greater and less than $\frac{1}{2}$. But, in fact, this is not so, as a glance at the data in Ref.5 will show, and in particular the structural targets tend to have a value of n of $\frac{1}{3}$ leading to the nonsensical answer, on the above analysis, that the best way of attacking these targets is with a cluster of small bomblets. The reason why the above analysis leads to such a false conclusion is discussed in the main text, section 2.4, but in essence it stems from the fact that the power law of equation (4) breaks down for values of W below a certain 'threshold value' and this threshold value can be very large, say of the order of 1000 lb, for major structural targets.

Appendix B

TARGET VULNERABILITY DATA

B.1   Tank target

B.1.1 Direct hits

Fig.5 plots the conditional kill chance for a direct hit on a typical
tank target as a function of charge diameter for a shaped charge projectile.
This curve typifies a complication to the direct-hit portion of the target
vulnerability curve of Fig.1 which applies to most targets, namely that some
parts of the target are more vulnerable than others and that the percentage
of target area vulnerable to a direct hit is a function of warhead size. This
does not, of course, invalidate the curve of Fig.1 nor the ensuing arguments
given in the main text, it merely means that we can choose various levels of
this direct-hit portion for different conditional kill probabilities and the
choice still remains open to choose a level corresponding to 100% conditional
kill chances. Fig.5 suggests that a tank target can be killed by a warhead
whose H.E. weight is in the range $\frac{1}{2}$ to 5 lb (2 inch to 6 inch charge diameter)
corresponding to conditional kill chances from 25% to 70%.

B.1.2 Near misses

Fig.6 plots estimates from various sources of lethal range as a function
of H.E. weight for near-misses against the same tank target, indicating for
instance that at 20 ft from the centre of the tank the critical H.E. weight
for a kill is in the range 100-1000 lb according to source and damage level
and that it increases as the cube of the miss distance.

B.2   AIRCRAFT TARGET

B.2.1 Direct hits

For internal detonations within an aircraft on the ground the H.E. weight
varies between $1\frac{1}{2}$ lb and 3 lb over a substantial portion of the target. For
hits involving detonation on the skin of the target trials results available
suggest that the amount of H.E. required can vary from $3\frac{1}{2}$ lb to 5 lb on a
fighter type and from 5 lb to 20 lb on bombers, depending on the part of the
target struck. This is shown diagrammatically in Fig.7 where the fighter fuselage
radius is arbitrarily taken as $2\frac{1}{2}$ ft and the bomber fuselage as $4\frac{1}{2}$ ft radius.

B.2.2 <u>Near-misses</u>

Trials in which aircraft were damaged by external blast have been inten-
sively analysed by Boulton[6], who deduced that for major structural damage the
lethal range measured from the centre line of the nearest part of the aircraft
structure was proportional to the square root of the weight of explosive. The
factor of proportionality varied with the type of target, even the part of the
target struck and also to some extent with the angle of impingement. Fig.7
illustrates the variation of lethal distance and warhead weight for external
blast warheads against hard and soft parts of the aircraft.

The lethal range of a well designed continuous rod can be taken to be of
the same order as the maximum hoop radius and for a given weight this depends on
the cross section of metal. Fig.7 shows broadly the variation of warhead weight
and lethal radius of the continuous rod against aircraft targets. There are
believed to be practical difficulties in making an effective rod warhead below
the minimum weight shown in Fig.7. Trials results show that the structural
damage by a rod depends on the nature of the target structure at the section
struck, but very broadly they confirm the indication in Fig.7 that a continuous
rod warhead of a given weight will have a longer damage radius than a blast
warhead. However, it must be remembered that rod warheads are not 'isotropic'
warheads such as blast warheads are and they involve a matching problem of burst
point relative to target.

B.3   BRIDGE TARGET

B.3.1 <u>Direct hits</u>

Fig.8 plots conditional kill chance for hits on a single-lane all-truss
bridge as a function of H.E. weight, indicating a threshold H.E. weight of the
order of 1000 lb.

B.3.2 <u>Near-misses</u>

For data on near-miss effects by blast against bridges we have to go to
nuclear sized charge weights and Ref.7 gives a curve for a truss bridge of
150-250 ft span indicating that to cause 50% probability of severe damage
requires at a distance of 300 ft, the lowest point on the curve, an equivalent
H.E. weight for blast of 400 000 lb and increasing as the cube of the distance.
The same reference suggests that ground shock will require even bigger charges,
e.g. 10^6 lb at 300 ft, scaling again as the cube of the distance. It should be
noted that 'near'-misses is a misnomer for the nuclear data quoted above since

the scaling law will break down for miss-distances small enough to be of
interest for non-nuclear weapons. This is due to the fact that the quoted
scaling law, based as it is on peak over-pressure, does not take into
account the variation of blast duration with charge weight. It is not pos-
sible therefore to fill in the bridge vulnerability curve for miss-distances
between zero and the 300 ft mentioned above, since the necessary data from a
relevant range of H.E. explosions does not exist.

B.4   Ship targets

B.4.1 Direct hits

Fig.9 suggests that the threshold size of M.C. warhead to cause
Category B damage with a direct hit on a destroyer is of the order of
1000 lb, i.e. about 500 lb of H.E. detonated internally.

B.4.2 Near-misses

Again for **air-burst** near-miss data we have to go to nuclear weapons
and Ref.7 gives a curve showing a lethal range of about 900 ft for a 1 kiloton
air-burst. 1 kiloton is roughly equivalent in blast to 10^6 lb of H.E. so the
above-mentioned curve suggests a lethal range **for nuclear weapons** of $9C^{\frac{1}{3}}$ ft
where C is the equivalent H.E. charge weight in lb. For the reasons given in
section B.3.2 this relationship cannot be used for air-burst miss-distances of
interest to H.E. weapons but for instance at 300 ft miss-distance it would give
a critical H.E. weight of 40000 lb. For **under-water** burst the near-miss portion
of the vulnerability curve can be based on the well-known shock factor $C^{\frac{1}{2}}/R$
where C is the charge weight and R is the lethal range. This factor
varies from 0.2 to 2 according to the target type and the damage category
being considered, but whatever the value it means that on this portion of
the vulnerability curve C increases as R^2. However, for the reasons
discussed in section 2.5 of the main text, the curve may start in the region
of, or even lower than, the threshold size for internal detonations.

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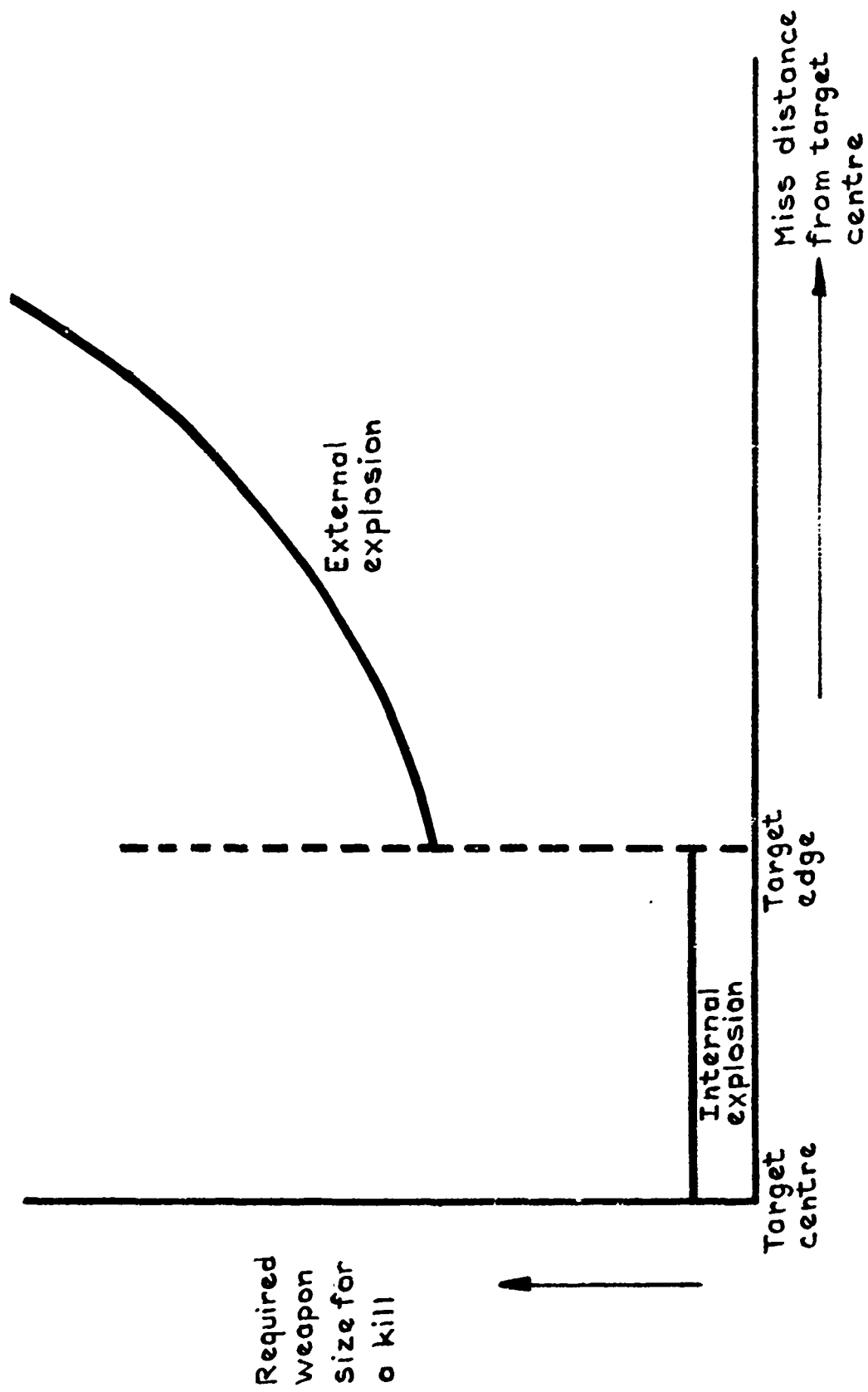
WE.R 8958

Fig.1

Fig.I Required weapon size as a function of miss distance

Fig.2
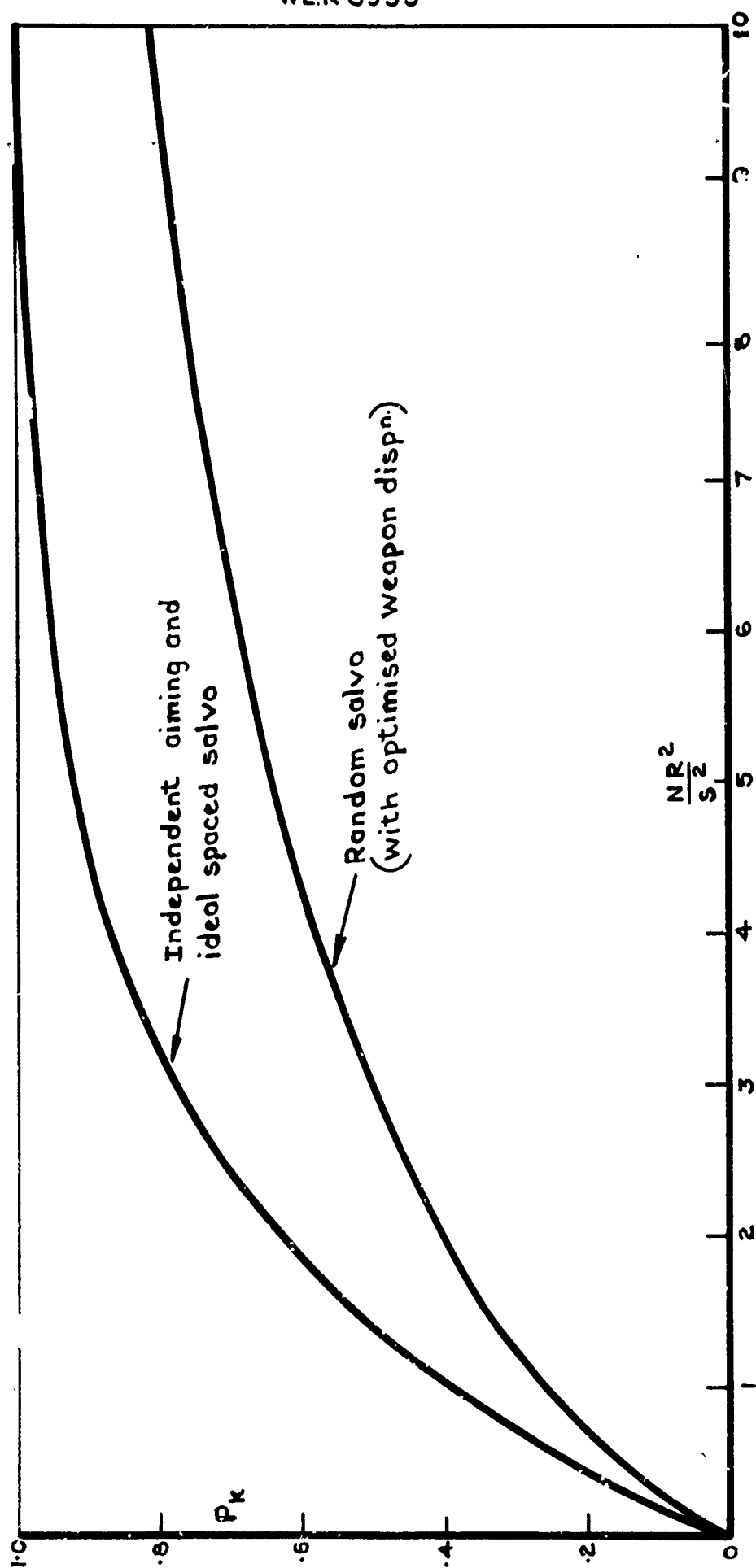
Fig. 2 Variation of P_K with $\dfrac{NR^2}{S2}$ for different weapon delivery modes
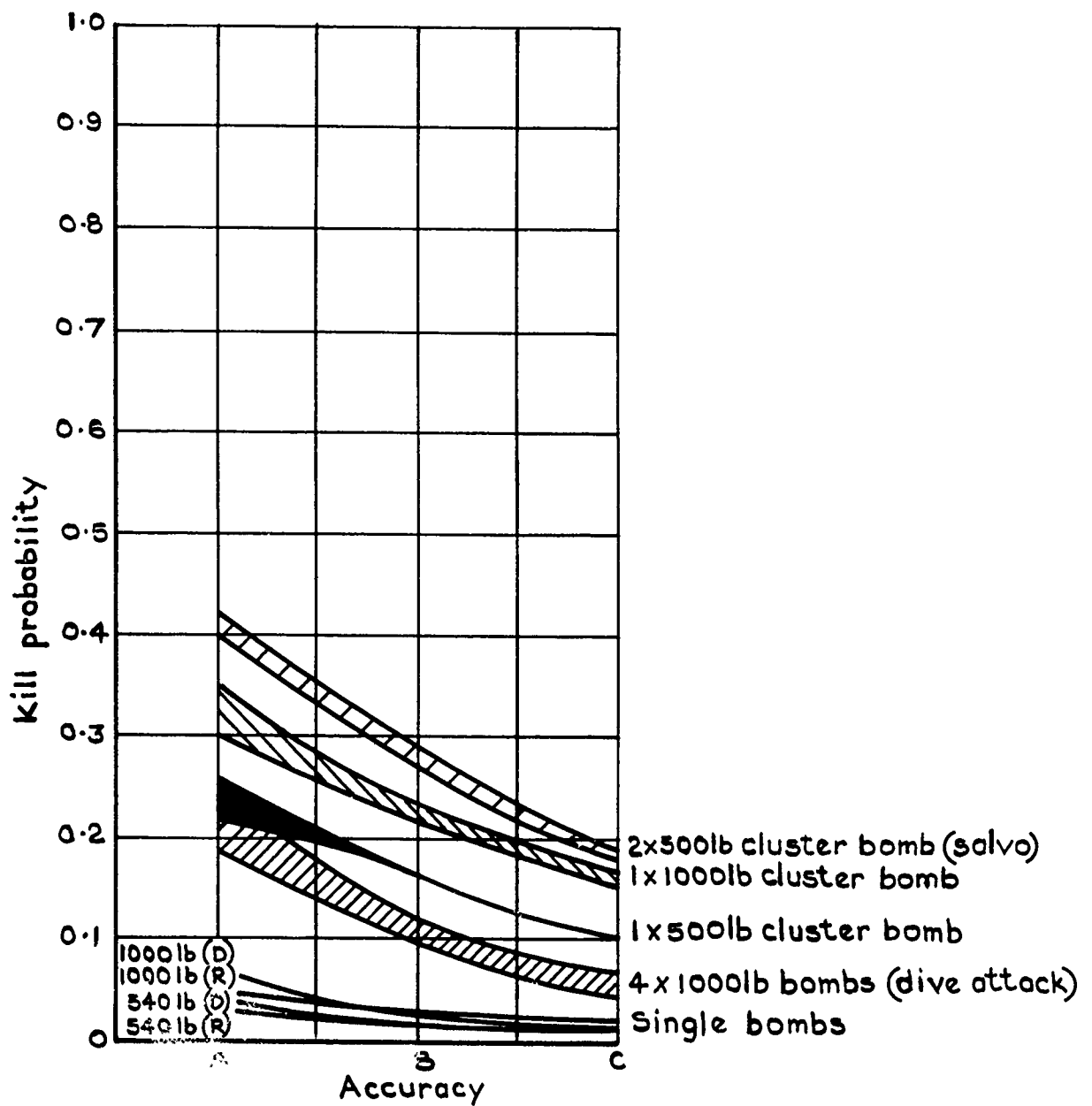
Fig.3 Comparison of cluster bombs and
bombs against a tank

Fig.4

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WE.R 10022
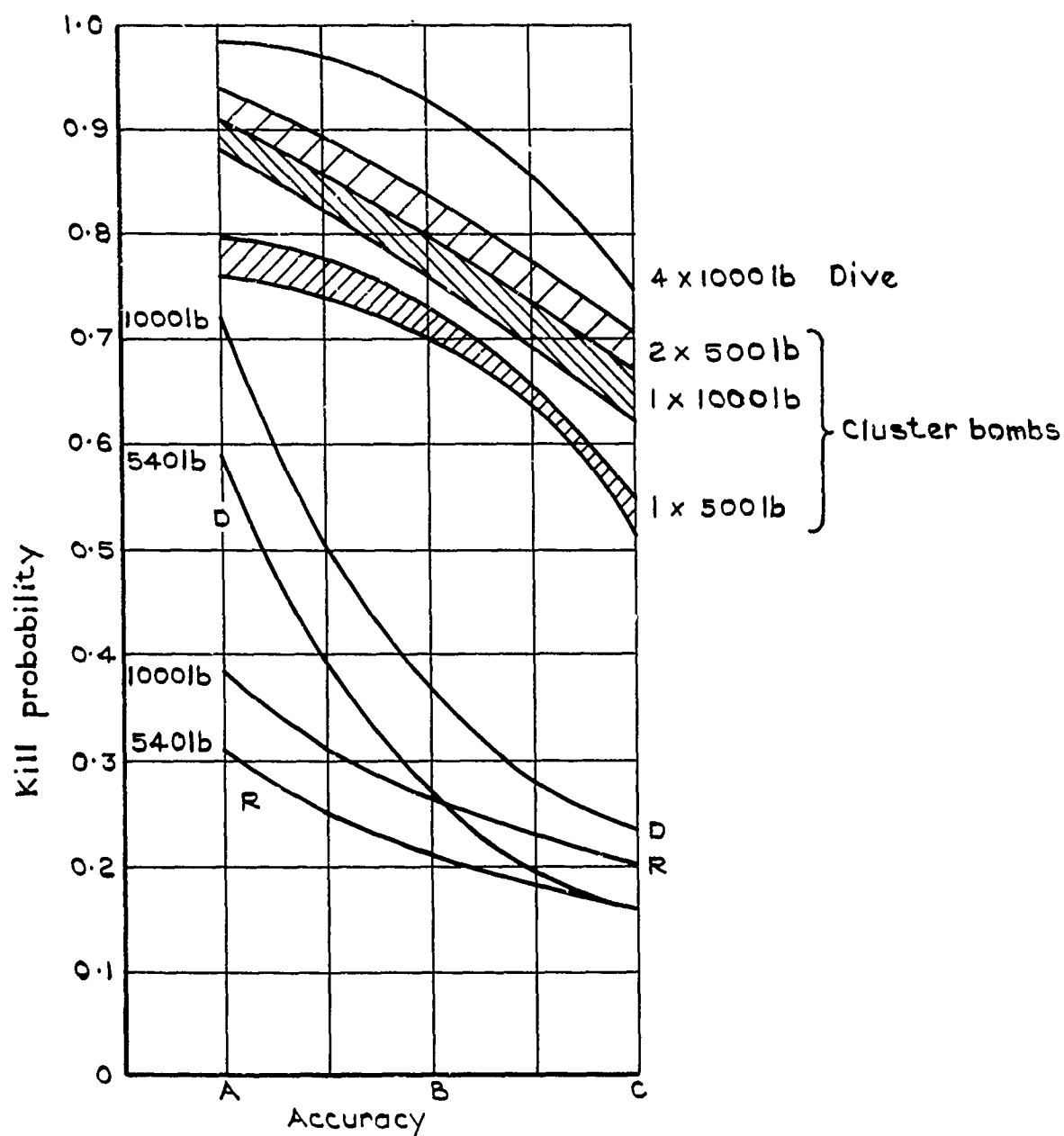
Fig. 4 Comparison of cluster bombs and
bombs against a parked aircraft

Fig.5

J. S III basic tank

Conditional kill chance practically constant for elevation angles 0° - 30°

Conditional kill chance (M or F or K)

Elevation angle	Total presented area (sq ft)
0	119
10°	131
20°	144
30°	157
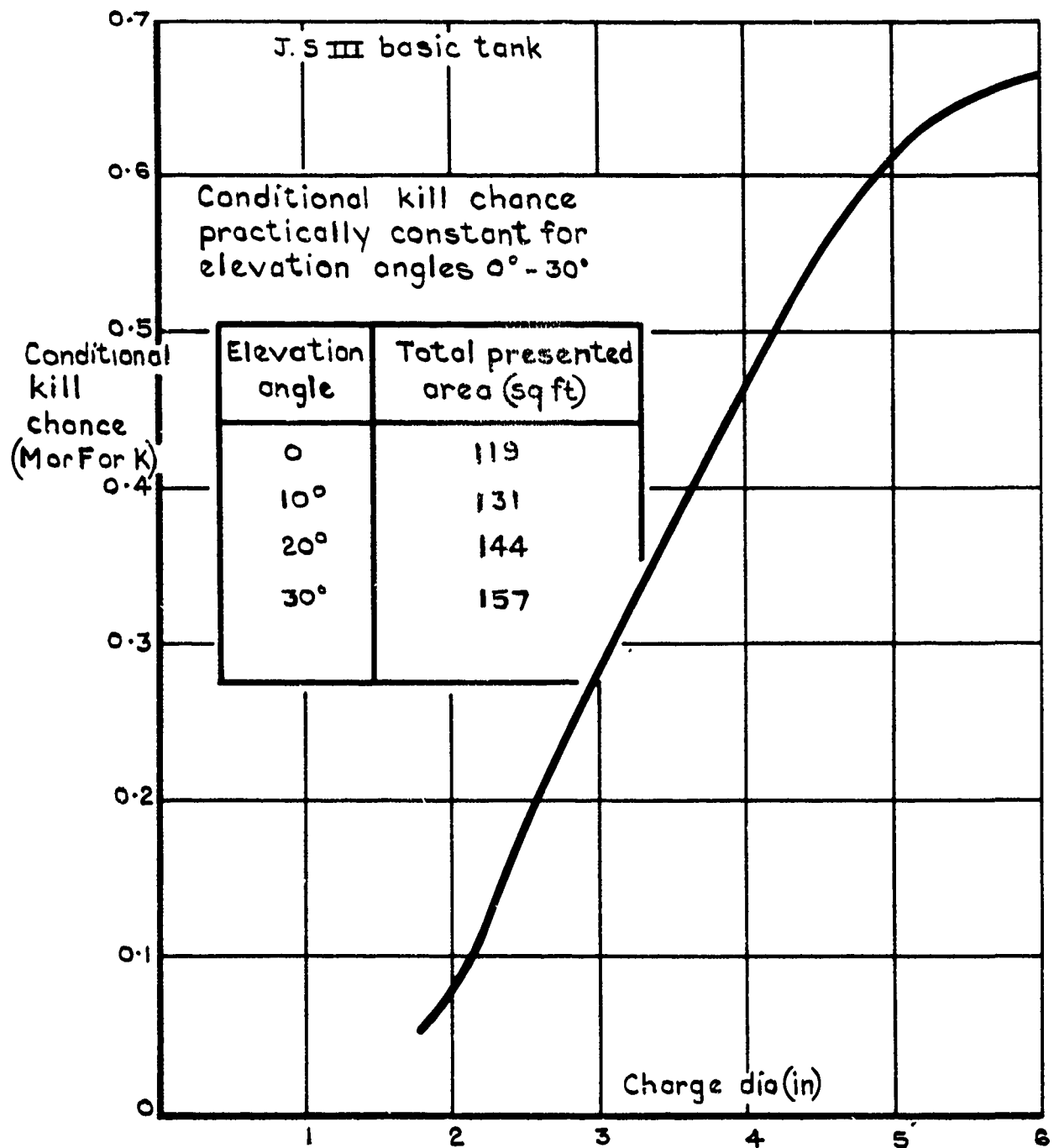
Charge dia (in)

Fig.5 Tank target : direct hits :
Conditional kill chance v charge dia

Fig.6

SECRET DISCREET
WER 9869
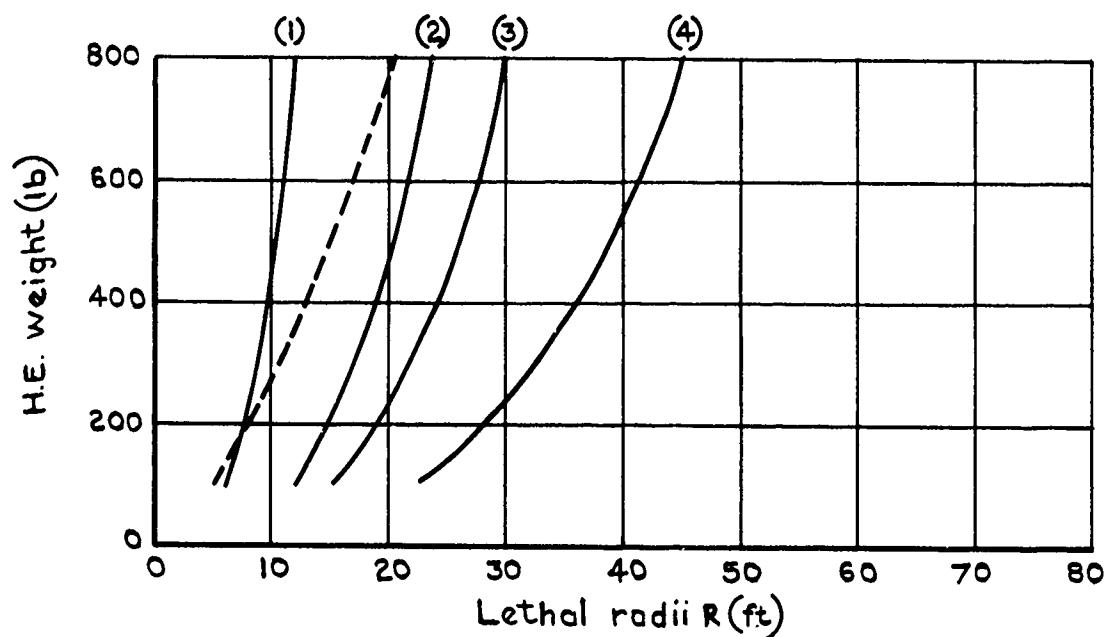
(1) O.E.G. Study : Complete or partial lack of fire power due to direct hit on vulnerable area $(R = 1 \cdot 3c^{1/3})$

(2) O.B. & A.O.R.G. $(R = 2 \cdot 6c^{1/3})$

(3) O.E.G. Study : Immobilization from near miss $(R = 3 \cdot 2c^{1/3})$

(4) R.A.R.D.E: Extrapolated from shell damage : Irreparable by crew in the field $(R = 4 \cdot 9c^{1/3})$

— — — Nots blast criterion $(R = \cdot 24c^{2/3})$

Fig.6 Tank target: lethal radii for near misses

Fig.7

Blast
warhead

Continuous
rod warhead

Hard region | Soft region | $\frac{1}{4}$" rod | $\frac{3}{16}$" rod
of target | of target

400

Required weight (lb)
of H.E. for blast curves
of total warhead for
continuous rod curves

100

Major structural damage
to targets on ground

10

Bomber

Dircect
hit
region

Near
miss
region

Fighter

Distance from ₵ of fuselage (ft)

1

1   Edge of Edge of   10   100   200
        fighter bomber
        target   target

Fig.7 Aircraft target vulnerability curve

Fig. 8
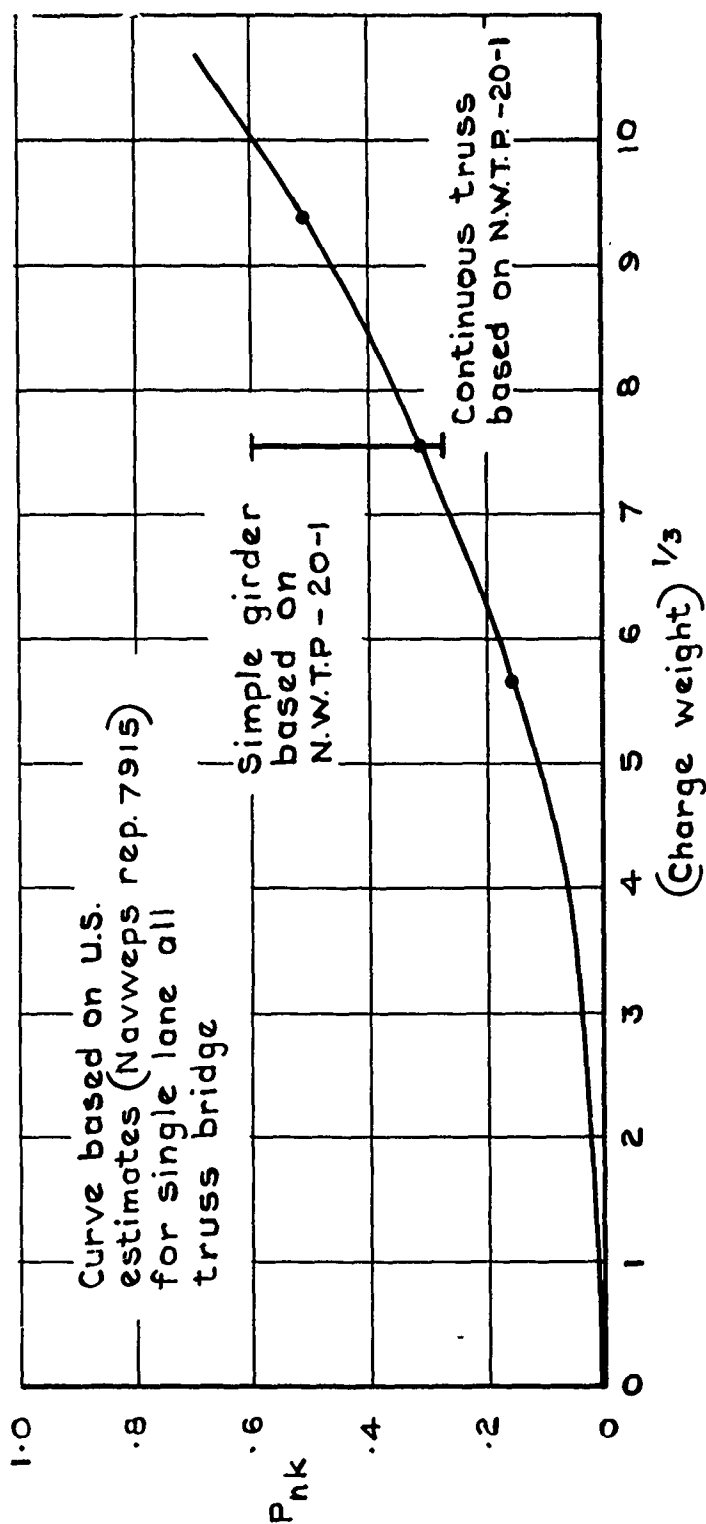
Fig. 8 Bridge target: direct hits: conditional kill probability estimates for H.E. warheads

Based on results in T.B.A.A. pt 2 chap 5

Light fleet carrier damage: at least serious (cat B)

Light fleet carrier damage: sunk (cat A)

Destroyer damage: (cat B)

Freighter (6000 ton gross) damage: sunk (cat A)

Destroyer damage: (cat A)

Tanker damage (cat A)

Broken line indicates extrapolation by R.A.E.

Probability of damage given a hit

Weight of warhead (lb)
these refer to M.C. or G.P. type warheads
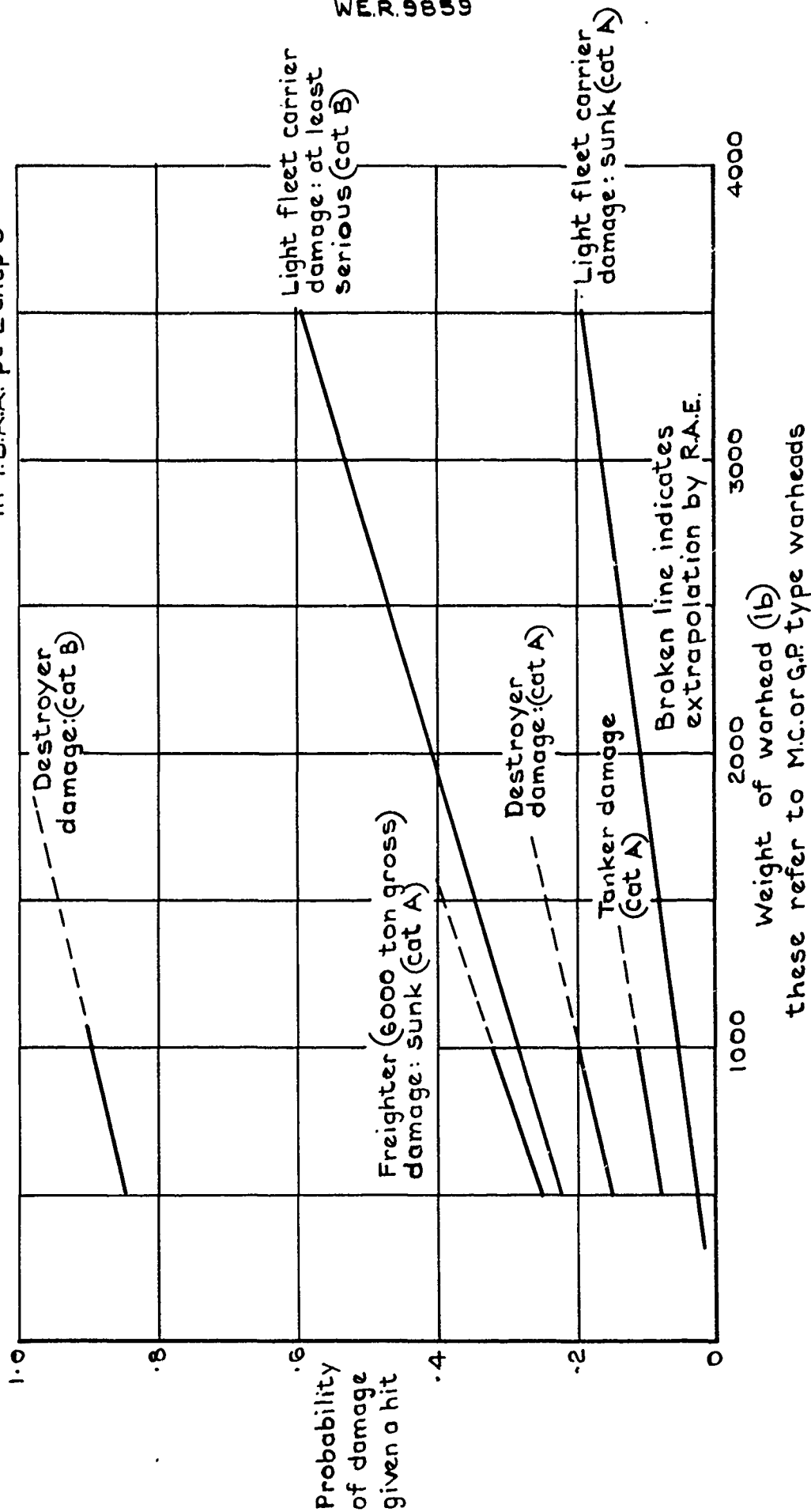
Fig.9 Ship target: direct hits: conditional kill probabilities for various types of ships (British estimates)

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that for weapons which have to be delivered in one attack opportunity, e.g. unguided air-to-surface weapons, the most efficient attack is with a spaced salvo of threshold weapons.

It is not claimed that the hypothesis is universally true. Whether it leads to a more effective weapon in any specific case will always require evaluation. Furthermore, it may be more applicable to air-to-surface weapons, mainly referred to as examples in this paper, than to other weapon types, such as anti-aircraft weapons, for which the warhead is a less dominant component.

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